

Management of Hazardous Waste Resulting from Chemical Experiments in Biotechnology

Deyun Ma^{1,a}, Liang Qin^{1,b}, Jing Zheng^{1,c}, Junxiao Zhu^{1,d}, Fenglan Liang^{2,e,*}, Rimeng Chen^{3,f}

¹School of Food and Pharmaceutical Engineering, Zhaoqing University, Zhaoqing, 526061, China

²College of Life Science, Zhaoqing University, Zhaoqing, 526061, China

³Zhanjiang Institute for Food and Drug Control, Zhanjiang, 524008, China

^amady@zqu.edu.cn, ^bliangq@zqu.edu.cn, ^c20212110030@stu.gzucm.edu.cn, ^dzhujunxiao@zqu.edu.cn,

^eliangfl82@126.com, ^f107779934@qq.com

*Corresponding author

Abstract: University laboratories are vital for teaching and research in science and technology, and are crucial for sustainable development. Chemistry labs are key for biotechnology students, using various regulated chemicals for experiments, some of which can produce hazardous waste. This paper uses a biotechnology chemistry lab as a case study to analyze hazardous waste characteristics and discusses its recycling and treatment principles. Furthermore, it addresses the current challenges associated with the disposal of chemical experimental waste by proposing appropriate solutions and management strategies. The aim is to offer a theoretical foundation and practical guidance for the standardized treatment of laboratory waste, thereby serving as a reference for chemical laboratories encountering similar issues.

Keywords: Biotechnology, Chemical Experiments, Toxic Waste, Processing Methodology, Management

1. Introduction

Amidst global competition in science and technology and rapid economic integration, China is advancing life sciences and developing expertise. This has led to an expansion of biology programs and a surge in enrollments, creating new challenges for biotechnology lab safety. New and updated labs must address emerging technical and safety issues. Additionally, to meet societal demands for practical skills, colleges are emphasizing practical teaching, with labs playing a key role in developing students' competencies [1-2]. As essential venues for the facilitation of experimental instruction and scientific research, chemistry laboratories necessitate the regular use of substantial quantities of chemical reagents. This practice inevitably results in the production of diverse forms of chemical waste, including liquid waste, solid residues, and other experimental by-products [3].

Chemical laboratory waste management in colleges faces major challenges: (a) Varying levels of environmental education among students result in inconsistent awareness and improper waste disposal [4]. (b) Many university labs have outdated infrastructure, lacking proper facilities for waste collection and storage. Containers often have poor sealing, are prone to leaks, and are not properly labeled [5]. (c) Limited Treatment Capacity: Universities outsourcing waste liquid treatment face challenges due to a shortage of qualified treatment enterprises and a limited range of processable waste liquids. (d) Increasing Cost Pressure: Rising treatment costs have financially strained universities. Complex and variable waste compositions, if not properly treated, risk overwhelming municipal wastewater systems with pollutants. Unregulated sewage discharge threatens environmental quality and public health, posing safety risks and ecological dangers. This highlights the urgent need for better management of chemical lab waste in colleges and universities. Standardizing waste management is vital for green chemistry, boosting environmental awareness, conserving resources, and improving researchers' experimental skills. Therefore, researching lab waste treatment methods is highly valuable [6].

2. Characteristics of waste generated in chemical laboratories

Experimental waste from college and university chemistry labs typically has these traits: (1) Limited production: Despite using various chemical reagents, the waste generated is generally small in

quantity. (2) Complex composition: The diverse reagents lead to waste with a varied and complex mix of pollutants. (3) Diverse classification: Waste is categorized by chemical nature-organic, inorganic, biological-and by physical form-gaseous, liquid, solid. Notably, organic waste often contains volatile organic solvents, which easily evaporate and are challenging to manage ^[7].

3. Principles of Waste Disposal in Chemical Laboratories

(1) Recycling and Reuse Priority: Research institutions and laboratories should establish a comprehensive recycling system for laboratory chemicals, focusing on classifying and recovering hazardous waste to reduce environmental risks and disposal costs. They should implement a laboratory-level recycling program for organic solvents, enabling reuse through distillation. They should also design experiments that use waste from previous experiments as raw materials, thereby creating a closed-loop system ^[8]. (2) Source Reduction and Control: Research institutions and laboratories should promote "green chemistry" education and integrate environmental awareness into experimental teaching. They should promote micro- and semi-micro-scale experimentation to reduce reagent consumption and limit the use of toxic reagents, favoring eco-friendly alternatives ^[9]. (3) Research institutions and laboratories should treat non-recyclable waste to meet emission standards and establish a system for separate collection based on hazardous characteristics ^[10]. (4) Research institutions and laboratories should use distinct collection containers with clear guidelines and prohibit the mixing of incompatible wastes. (5) Research institutions and laboratories should store waste in professional sealed containers for safe transport and implement a waste ledger system to ensure traceability. (6) Collaborative Disposal Mechanism: Research institutions and laboratories should create a sustainable framework with certified disposal professionals to regularly exchange disposal technologies and improve waste management. (7) Strategies for Specific Challenges: Research institutions and laboratories should develop specialized disposal methods for difficult hazardous wastes and collaborate with external research institutions for tailored solutions when necessary. They should establish a standardized system for recycling and disposing of laboratory hazardous waste to ensure safe and eco-friendly practices ^[11].

4. Common methods for waste collection and treatment

Chemical laboratory waste is typically varied, concentrated, complex, and prone to chemical changes, necessitating a systematic collection approach for effective management. Collection methods include ^[12]: 1) Classification Collection, which separates waste by type (solid, liquid, gaseous); 2) Quantity-Based Collection, which stores large or recyclable waste in designated containers and disposes of small or non-recyclable waste in waste liquid tanks; and 3) Similarity Categorization, which groups waste with similar chemical properties and treatment needs. 4) Centralized Method: This method is used for collecting precious metals, enhancing waste management safety and efficiency, and minimizing environmental pollution risks. Chemical laboratory waste disposal is categorized as follows:

4.1. Method for the Treatment of Organic Waste Liquids

Organic waste liquids are divided into combustible, refractory, and aqueous types based on their properties ^[13]. Treatment methods vary according to the waste's characteristics and include incineration, solvent extraction, adsorption, hydrolysis, oxidative decomposition, and biochemical treatment. These methods fall into three main categories: physical (e.g., filtration, evaporation, reverse osmosis), chemical (e.g., coagulation, neutralization, electrolysis), and biological (e.g., activated sludge, biofilm). Selecting the right combination of treatments based on the waste's combustibility, solubility, and biodegradability is crucial for effective processing. Incineration is prioritized for combustible organic waste, chemical oxidation for recalcitrant organic waste, and biological treatment for aqueous organic waste. Depending on treatment goals, options like resource recovery, non-hazardous treatment, or volume reduction may also be chosen ^[14].

4.1.1. Common waste liquid from organic reagents

In chemical labs, organic waste liquids like alcohols, esters, and ketones require specific disposal methods. Flammable liquids should be sealed, stored at low temperatures, and incinerated, while low-concentration flammable wastes can undergo solvent extraction or adsorption. Biodegradable substances, such as methanol and ethanol, can be diluted and discharged. Volatile, toxic solvents like

chloroform should be covered with a water layer to reduce evaporation and be stored at low temperatures before professional disposal ^[15].

4.1.2. Waste liquids containing sulfur, nitrogen, and halogen functional groups

This waste liquid mainly contains organic compounds like pyrimidine, pyridine, imidazole, and others, including dyes and pesticides. Treatment should match the waste's characteristics. Combustible liquids can be burned, but emissions such as SO₂, HCl, and NO₂ must be controlled with a tail gas treatment system. For difficult-to-treat substances or low-concentration waste, laboratories should use extraction or adsorption methods.

4.1.3. Phenol-containing waste liquid

This waste liquid mainly contains phenol, cresol, and naphthol. Treatment methods vary with phenolic concentration: high concentrations can be incinerated or processed with butyl acetate extraction and sodium hydroxide, followed by distillation and purification for recycling. Low concentrations can be treated with oxidation (using bleach or sodium hypochlorite), adsorption, or extraction. During the synthesis of p-nitrophenol and phenolphthalein, phenolic levels often exceed limits, requiring special oxidation treatment ^[16].

4.1.4. Waste liquids containing benzene and grease

The waste liquids mainly consist of hydrocarbons like benzene, hexane, toluene, and xylene, along with petroleum products such as paraffin and various oils. They also include industrial oils, greases, and animal and plant fats. Treatment should be tailored to their properties: combustible wastes should be incinerated, while refractory and low-concentration wastes are better suited for extraction or adsorption. Special waste liquids with oil and heavy metals need proper storage and should be handled as incineration residues by specialized companies ^[17].

4.1.5. Waste liquids containing polymers

The waste liquids mainly consist of synthetic polymers like polyethylene and natural polymers such as lignin and starch. Treatment should match the waste's characteristics. Flammable liquids are usually incinerated, but synthetic rubber, PVC, and protein can release harmful gases, requiring exhaust gas treatment. Refractory or low-concentration wastes should be concentrated before incineration. In contrast, liquids with biodegradable substances like starch can be safely discharged after proper dilution ^[18].

4.2. Method for the Treatment of Inorganic Waste Liquids

The main inorganic waste liquids from chemical labs include those with cyanides, acids, alkalis, and various metal compounds like chromium, mercury, arsenic, lead, cadmium, and silver. At Zhaoqing University's School of Life Sciences, we have summarized the types and amounts of potentially hazardous waste liquids from our inorganic chemistry experiments ^[19].

4.2.1. Cyanide-containing waste liquids

Cyanide and its derivatives, known for their toxicity, are often used as ligands in labs because of the CN⁻ ion's excellent coordination abilities. Cyanide-contaminated waste can be treated using ligand precipitation by first adjusting the pH to 10 with lime, then adding iron sulfate to form the stable Fe(CN)₆⁴⁻ complex, effectively detoxifying the waste ^[20].

4.2.2. Acid and alkali waste liquid

Acidic and alkaline waste liquids are treated through neutralization. First, the waste is sorted and collected based on its acidity or alkalinity. Then, the liquids are mixed in precise ratios while monitoring the pH with test paper or a portable meter, aiming for a neutral pH of 7. If neutrality isn't achieved, industrial alkali or concentrated acid is added to adjust the pH to meet safety standards ^[21].

4.2.3. Waste liquid containing chromium compounds

To address the failure of the green chromic acid wash solution, concentrate and cool it, then add potassium permanganate powder for oxidation, turning the solution dark brown or slightly purple. Filter through a sand core funnel to remove manganese dioxide precipitate, enabling regeneration. If the solution is blackened, reduce residual Cr⁶⁺ to Cr³⁺ using waste iron filings. Add waste lye or lime to form low-toxicity chromium hydroxide precipitate, ensuring careful control of alkali dosage to prevent converting Cr(OH)₃ into soluble chromite ions (CrO₂²⁻), which would dissolve the precipitate ^[22].

4.2.4. Waste liquid containing mercury compounds

Laboratory mercury waste is categorized into elemental mercury and mercury-containing wastewater. Elemental mercury, from broken devices like thermometers, requires careful handling due to its toxic vapors, using good ventilation and droppers for collection. Mercury wastewater is treated with the sulphide co-precipitation method by adjusting its pH to 8-10, adding Na_2S to form HgS precipitate, and using FeSO_4 and more Na_2S to create FeS , which helps co-precipitate HgS through adsorption. After static precipitation, the supernatant is decanted off, and the precipitate is collected. The residue undergoes centrifugation and filtration, and the Hg^{2+} concentration in the filtrate is checked to ensure regulatory compliance before discharge. Precipitates must be carefully collected and disposed of safely [23]. For more toxic organic mercury wastewater, concentrated nitric acid and 6% potassium permanganate are used to oxidize and decompose the organic mercury through heating and reflux. Additional potassium permanganate is added as needed until the organic mercury is fully converted into mercury ions. The resulting solution is then treated like inorganic mercury.

4.2.5. Waste liquid containing arsenic compounds

Arsenic-laden wastewater can be treated using two main methods. The first involves adding slaked lime to raise the pH to 9, converting arsenic into calcium arsenate or arsenite precipitates, followed by FeCl_3 to form $\text{Fe}(\text{OH})_3$ for co-precipitation. The second method raises the pH above 10 and adds sodium sulfide to form insoluble arsenic sulfide precipitates. Both effectively remove arsenic from the solution [24].

4.2.6. Waste liquid containing lead and cadmium compounds

Wastewater with lead and cadmium is treated by adjusting its pH to 8-10 using lime, converting Pb^{2+} and Cd^{2+} ions into lead and cadmium hydroxide precipitates. Ferrous sulfate is added to improve precipitation. The clarified liquid is discharged per regulations, while the precipitate is mixed with other inorganic wastes for high-temperature sintering and curing [25].

4.2.7. Waste liquid containing silver compounds

Silver-containing waste liquids, mainly from silver analysis, mirror reactions, and electroplating, often appear as AgNO_3 and $[\text{Ag}(\text{NH}_3)_2]^+$. The treatment involves adjusting the waste liquid to an acidic pH, adding saturated brine to convert Ag^+ into AgCl precipitate, filtering, and washing the precipitate with dilute nitric acid multiple times. Once dried, the precipitate can be recycled. This simple method is ideal for lab use [26].

4.3. Method for the treatment of waste gas

The laboratory exhaust gases include over a dozen types, mainly H_2S , CO , Cl_2 , H_2 , O_2 , N_2 , CO_2 , CH_4 , HCl , Br_2 , SO_2 , NO_2 , and NH_3 . Notably harmful ones are Br_2 , NO_2 , Cl_2 , H_2S , HCl , SO_2 , and CO . Addressing these emissions requires a tiered approach. Minor toxic gases are diluted and dispersed via fume cupboards or ventilation ducts positioned high for effective dispersion. Larger volumes of harmful gases need purification through absorbers, using either solution adsorption with liquid absorbents like water, oxidants, acid-base, or organic solutions, or solid absorption methods [27]. The solid absorption method uses materials such as activated carbon, molecular sieves, or diatomaceous earth to treat low concentrations of pollutant gases [28].

4.4. Method for the treatment of solid waste

Solid waste from chemical labs mainly includes leftover reagents, precipitation residues, broken glassware, consumables like gauze and filter paper, and expired chemicals, often containing toxic substances and heavy metals. Despite their small quantity, these wastes are complex and hazardous. Improper disposal, such as mixing with household waste, can lead to significant soil and water pollution. Therefore, it is crucial to segregate and dispose of these wastes safely. Flammable waste should be incinerated, while non-flammable waste must be treated with chlorination and disinfection before final disposal to comply with regulations [29]. Biological waste requires strict treatment, including centralized incineration of disposable lab supplies per established codes. Reusable glassware should be rinsed after soaking in a chlorine solution (1000-3000 mg/L) for 2-6 hours. Standard glassware should be sterilized by boiling for 15 minutes. Petri dishes for microbiological cultures and agar plates for inoculation must be autoclaved, and agar plates should be discarded while still hot after 30 minutes.

4.5. Method for the treatment of special waste

Radioactive waste includes materials contaminated with radioactive substances that are no longer usable. Managing this waste involves categorizing and disposing of it based on contamination levels and characteristics. Contaminated instruments and metals can be reused after decontamination. Combustible waste is incinerated, with ash securely contained, while non-combustible waste is compacted and stored for permanent disposal. Disposable items are incinerated after being bagged. Agar plates are pressure sterilized and discarded hot. Animal carcasses and bedding are sterilized with glutaraldehyde; carcasses are preserved in formaldehyde for incineration, while sterilized bedding can be discarded as domestic waste ^[30].

5. Guidelines for the secure conduct of chemical experiments in the field of biotechnology.

Ensuring a safe laboratory environment requires active involvement and structured management. First, it's crucial to set up an effective management system and oversight to standardize biotech lab operations, possibly through annual safety agreements. Second, a specialized team of safety professionals should be formed to regularly inspect waste management and create standardized recycling processes. Many colleges and universities currently struggle with inadequate frameworks and a lack of skilled safety management personnel. Institutions can improve by adopting practices from top international universities, including setting up a dedicated safety management team, creating a robust management system, and outfitting labs with specialized testing equipment. It's also important for technical experts and managers to earn professional health and biosafety qualifications. These steps will significantly enhance the management of laboratories, especially biosafety labs ^[31].

6. Innovative Approaches to Waste Disposal in Biotechnology Laboratories

Using Zhaoqing University as an example, the toxic waste from biotechnology experiments over the past three years highlights the urgent need for reduction measures, focusing on three main strategies.

6.1. Performing virtual simulation experiments

The Virtual Simulation Experimental Teaching Centre, launched on 10 July 2024, consists of four sections: a public teaching area, a professional training area, an experience area, and a research and creation area. These sections support diverse disciplines by simulating experimental procedures and reactions, offering an immersive experience. This approach is especially useful for high-risk toxic experiments and waste management, reducing costs and toxic emissions, thus promoting sustainable teaching ^[32].

6.2. Development of micro-experiments

To lessen environmental impact, apply green chemistry by optimizing experiments. Laboratories should focus on miniaturized designs to reduce reagent use without losing effectiveness. They should avoid highly toxic chemicals and improve methods, especially with respect to solution concentrations. For example, in "Determination of Organic Compounds by High-Performance Liquid Chromatography," they should leverage its sensitivity to use low-concentration solutions, thereby achieving educational goals while cutting reagent use.

6.3. Enhancing environmental awareness

Effective waste management starts at the source by reducing liquid waste through standardized procedures and promoting good lab practices. Key strategies include using the differential weighing method for precise measurements, standardizing solution preparation with glass rods and colloidal burettes, and sealing volatile reagents with corks. These practices ensure accuracy and significantly reduce pharmaceutical and liquid waste. The lab technician, overseeing the experiment, is crucial in managing waste liquids by being environmentally conscious. They adjust reagent quantities based on person-hours to ensure adequate supply and minimize waste, applying a 'dispense-as-needed' approach for perishables. Distinct labels prevent medication mix-ups, reducing pharmaceutical waste and liquid waste generation through careful management and attention to detail ^[33-34].

7. Conclusion

In summary, managing and treating chemical experimental waste is crucial for sustainable labs, offering environmental and economic benefits through innovation and system optimization. Key strategies include improving waste classification and treatment, establishing regulations, enhancing operational standards, and developing recycling processes. These efforts reduce pollution risks and costs while promoting energy conservation and emission reduction, supporting a sustainable society and development goals.

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References

- [1] Zhu C. *Life sciences and biotechnology in China*[J]. *Science Progress in China*, 2003, 212-230.
- [2] Zhou P D, Qi F P. *Research on Chemical Experimental Waste Disposal in Colleges and Universities*[J]. *Science and Technology*, 2016, 01: 274+276.
- [3] Sun L. *Research on the Safety Management Mode of University Biological Laboratory by Strengthen the Cultivation of Independent Safety Awareness*[J]. *Journal of Physics: Conference Series*, 2023, 2468: 012137
- [4] Siril A J, Bakar S N A, Fatehah M O. *Hazardous Waste Management, Challenges, and Risks in Handling Laboratory Waste in Universities*, *Handbook of Solid Waste Management: Sustainability through Circular Economy*[M]. Singapore: Springer Nature Singapore, 2022. 1655-1714.
- [5] Chen X. *Treatment and Management of Waste Liquid From Chemical Laboratories in Colleges*[J]. *Liaoning Chemical Industry*, 2016, 45(5): 635-637.
- [6] Jindal T, Ramanathan S, Lal R B. *Physicochemical Treatment of Research Laboratory Wastewater: A Case Study*[J]. *Emerging Issues in Ecology and Environmental Science: Case Studies from India*, 2019, 85-98.
- [7] Goh H Y, Wong W W C, Ong Y Y. *A Study To Reduce Chemical Waste Generated in Chemistry Teaching Laboratories*[J], *Journal of Chemical Education*, 2019, 97(1):87-96.
- [8] Twumasi A K, Nartey E, Quayson C, et al. *Chemistry students' knowledge and practices of chemical waste management in chemistry laboratories*[J]. *African Journal of Chemical Education*, 2023, 13(3): 21-41.
- [9] Oliveira D B, De Becker R W, Sirtori C, et al. *Development of environmental education concepts concerning chemical waste management and treatment: the training experience of undergraduate students*[J]. *Chemistry Education Research and Practice*, 2021, 22(3): 653-661.
- [10] Zahari M S M, Jaafar I, Ismail S, et al. *Laboratory waste management and treatment. Industrial waste engineering*[M]. Cham: Springer International Publishing, 2024, 397-439.
- [11] González V G, Velasco F E H, Candelo-Becerra J E. *Strategies for use, treatment, management and final disposition of wastes in academic laboratories*[J]. *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, 2020, 18(6): 3130-3141.
- [12] Leoneti A B, Santos D V dos, Silva R S da, et al. *Process management framework for chemical waste treatment laboratories*[J]. *Business Process Management Journal*, 2020, 26(2): 447-462
- [13] Kumareswaran K, Ranasinghe S, Jayasinghe G Y, et al. *Systematic review on liquid organic waste (LOW) characteristics, processing technologies, and their potential applications: Towards circular economy and resource efficiency*[J]. *Journal of Cleaner Production*, 2024, 141286
- [14] Bai F Q. *Safety Rules and Common Sense in the Chemistry Laboratory Lecture 4 Disposal of Waste Substances (above)*[J]. *Education and Equipment Research*, 2022, 18(7): 30-32.
- [15] Wan S. *Safe management of chemical reagents in chemical analysis laboratories*[J]. *Physical Testing and Chemical Analysis (Part B: Chemical Analysis)*, 2010, 46(6): 690-691.
- [16] Said K A M, Ismail A F, Karim Z A, et al. *A review of technologies for the phenolic compounds recovery and phenol removal from wastewater*[J]. *Process Safety and Environmental Protection*, 2021, 151: 257-289.
- [17] Pawlak Z, Rauckyte T, Oloyede A. *Oil, grease and used petroleum oil management and environmental economic issues*[J]. *Journal of Achievements in Materials and Manufacturing Engineering*, 2008, 26(1): 11-7.

- [18] Datta J, Kopczynska P. From polymer waste to potential main industrial products: Actual state of recycling and recovering[J]. *Critical reviews in environmental science and technology*, 2016, 46(10): 905-946.
- [19] Liu L H, Li J Y. Research study practice of toxic waste treatment in chemistry experiments[J]. *Health Vocational Education*, 2004, 22(1): 109-110.
- [20] Martinkova L, Bojarova P, Sedova A, et al. Recent trends in the treatment of cyanide-containing effluents: Comparison of different approaches[J]. *Critical Reviews in Environmental Science and Technology*, 2023, 53(3): 416-434
- [21] Liang D, Wang F, Xue S, et al. Purification of waste liquids from alkaline washing pretreatment of municipal solid waste incineration fly ash using Friedel's salt[J]. *Journal of Environmental Management*, 2025, 380: 125020.
- [22] Walawska B, Kowalski Z. Environmental evaluation of the effects of using chromic waste in the production of chromium compounds[J]. *Journal of Cleaner Production*, 2001, 9(3): 219-226
- [23] Rodríguez O, Padilla I, Tayibi H, et al. Concerns on liquid mercury and mercury-containing wastes: A review of the treatment technologies for the safe storage[J]. *Journal of environmental management*, 2012, 101: 197-205
- [24] Nguyen T V, Loganathan P, Vigneswaran S, et al. Arsenic waste from water treatment systems: characteristics, treatments and its disposal[J]. *Water Science and Technology: Water Supply*, 2014, 14(6): 939-950
- [25] Gharabaghi M, Irannajad M, Azadmehr A R. Leaching behavior of cadmium from hazardous waste[J]. *Separation and Purification Technology*, 2012, 86: 9-18
- [26] Chen L H. Discussion on green chemistry experiment and environmental protection[J]. *Journal of Huaibei Coal Industry Teachers College*, 2003, 24(3): 66-69+74
- [27] Syed S. Silver recovery aqueous techniques from diverse sources: Hydrometallurgy in recycling[J]. *Waste management*, 2016, 50: 234-25
- [28] Sun Y, Zwolinska E, Chmielewski A G. Abatement technologies for high concentrations of NO_x and SO₂ removal from exhaust gases: A review[J]. *Critical Reviews in Environmental Science and Technology*, 2016, 46(2): 119-142.
- [29] Jiang Y P. Principles and methods of laboratory waste recycling and disposal[J]. *Experiment Teaching and Apparatus*, 2011, 7: 116-118.
- [30] Hamer G. Solid waste treatment and disposal: effects on public health and environmental safety[J]. *Biotechnology advances*, 2003, 22(1-2): 71-79.
- [31] Choppin G R, Khankhasayev M K. Chemical separation technologies and related methods of nuclear waste management: applications, problems, and research needs (Vol. 53)[M]. Springer Science & Business Media, 1999.
- [32] Abedsoltan H, Shiflett M B. Mitigation of potential risks in chemical laboratories: A focused review. *ACS Chemical Health & Safety*, 2024, 31(2): 104-120.
- [33] Hou Y, Wang M, He W, et al. Virtual simulation experiments: a teaching option for complex and hazardous chemistry experiments[J]. *Journal of Chemical Education*, 2023, 100(4): 1437-1445.
- [34] Time A. Proper Waste Disposal of Laboratory Wastes in Schools, *International Journal of Advances in Education*[J]. *Social Sciences and Innovation*, 2022, 1(1): 31-37.